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Evaluation of the Biogas Production Potential by Anaerobic Digestion of Fermentable Agricultural Residues in Côte d'Ivoire

Bodjui Olivier Abo*, Loissi Kalakodio and Moussa Bakayoko

Department of Environmental Engineering, University of Science and Technology Beijing, PR China

Abstract

Anaerobic digestion is the natural biological process of organic matter's degradation in absence of oxygen (anaerobic). In this work we estimated the potential of biogas production by anaerobic digestion of fermentable residues from agricultural origin in Côte d'Ivoire. To date, no quantitative estimation or physicochemical parameters of agricultural residues have been undertaken on a national scale in Côte d'Ivoire.

This work gives an initial contribution to the estimation of biogas production potential by the anaerobic digestion process of agricultural residues. It was developed on the basis of statistical data from FAO (Food and Agriculture Organization of the United Nations) and other structures related to agricultural production.

This study revealed that total agricultural residues were estimated to be more than 5.0 × 10^6 tons of organic matter or the equivalent of more than 10 × 10^8 m^3 of methane in terms of potential energy by anaerobic digestion. These results put forward opportunities such as access to energy for the benefit of the rural communities in Côte d'Ivoire by anaerobic digestion as well as more sustainable way of recovering agricultural residues available locally in significant quantities. Nevertheless, studies corroborated by field surveys will need to refine this assessment for smaller time intervals and considering a finer geographical mesh.

Keywords: Anaerobic digestion; Agricultural residues; Potential energy; Methane; Côte d'Ivoire

Introduction

Anaerobic digestion is the natural biological process of organic matter's degradation in absence of oxygen (anaerobic). Some of the organic matter is degraded to methane, and another is used by the methanogenic microorganisms for their growth and reproduction. The decomposition is not complete and leaves the "digestate".

Naturally, it occurs in some sediments, marshes, rice fields, and in the digestive tract of certain animals: insects (termites) or vertebrates (ruminants). Anaerobic digestion is also a technique artificially applied by men in digester where the process is accelerated and maintained to produce a usable methane (biogas, referred to as biomethane after purification).

The great interest of methanisation plants on farms is the diversification of their production, through the generation of renewable energy (from biogas) in the organic amendments' production through optimized treatment of the organic waste from the farm. Anaerobic digestion is particularly interesting in the context of precarious countries, as in the case of Côte d'Ivoire, not only because it contributes to the treatment of fermentable organic residues and to the management of pollution, but also because it offers, through its main products (biogas as a source of energy and solid digestate as an organic soil amendment), solutions and income- generating options. This method of treatment is applicable to a wide range of cellulosic organic wastes, including cow dung, poultry manure, pig manure, human excreta, plant residues, fermentable fractions of household refuse and industrial waste agri-foodstuffs are characterized by their aptitude for recovery by aerobic and anaerobic biological treatments and a relatively rapid decomposition especially in the climates of intertropical countries. Also, these residues contribute to the emission of unpleasant odors, air pollution, pollution of ground and surface waters, and the proliferation of insect vectors of diseases. Anaerobic digestion is therefore an interesting alternative especially for rural areas because of its potential for production from decentralized units requires no major infrastructure or financial means, but provides fertilizing and plant- protection material and mainly energy Thermal and electrical power in one of its most sustainable forms for small farms and farming communities [1-3].

Since the 1960s, numerous research and development projects have been carried out in different regions around the world in order to optimize traditional practices for the valorization of these categories of waste, in a movement similar to a "scientific and technological revolution" Of agricultural residues [4].

Indeed, this new paradigm, in the sense of Kuhn, began with the publications of Lampila and Wilson and Pigdon the development of technologies to improve the digestive properties of cereal straw in animal feeding, in Europe and North America, and from the 1980s to the developing tropical countries, in particular India, Bangladesh, Other countries in Asia and Africa [4].

In Côte d'Ivoire, no systematic quantification or biophysical-chemical characterization of organic fractions of agricultural waste has been carried out to date. While agricultural residues make a significant contribution to the realization of economic activities, particularly in the rural area, through various mechanisms for the exploitation of materials and energy [5]. The objective of the work is therefore to contribute to a

***Corresponding author:** Bodjui Olivier Abo, Department of Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, PR China, Tel: +86-10-62327878; E-mail: abobodjuiolivier@yahoo.com

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quantitative evaluation of the deposits of the main fermentable organic fractions of residues generated by agricultural activities in Côte d'Ivoire and their potential for energy recovery through anaerobic digestion. The methodological approach implies an underestimation of potentially available deposits, in the sense that the categories of residues taken into account do not pretend to be exhaustive. Moreover, at the level of the estimated ranges, pessimistic choices of the orders of magnitude by default were chosen.

Methodology

Description of ivorian agriculture

An assessment of the quantities of organic residues generated by the agricultural sector in Côte d'Ivoire implies putting the rural environment in perspective as the main reception area for the agricultural sector, the specific situation of agriculture and the logics according to which the residual fractions produced are recovered or eliminated.

The economy of Côte d'Ivoire is based on agriculture. In addition to its favorable climate and its luxuriant vegetation, it has been able to exploit a wide range of plant products (wood, coffee, cocoa, cotton, hevea, palm oil, cashew nut, pineapple, mango, papaya, sweet banana, sugar cane, coconut, yam, cassava, taro, plantain banana, corn, rice, sorghum, fonio, peanut, etc.) and to develop livestock production and fisheries.

The activities of the sector of agriculture, agri-food, crop, livestock, and agro-food industries account for an average of 27% of Gross domestic product (GDP) and provide 40% of export earnings. They are the main source of employment and income for the majority of the population, estimated at 66% on average.

Côte d'Ivoire is divided into two climatic zones. In the south, the coastal, subequatorial climate is marked by temperatures always above 18°C, high humidity and virtually zero thermal amplitude; Rainfall (2,500 mm on average) is divided between two rainy seasons (April-August and September-November); The temperatures, always high, oscillate between 21°C and 33°C. Towards the center of the country, rainfall is less abundant (from 1,000 to 2,500 mm) and the difference of temperatures is rather clearer mostly between 14°C and 39°C. In the north, the climate is of the Sudanese tropical type, with a weakly humid season and a dry season (November-May) under the influence of the harmattan (dry and warm Sahara wind); thermal amplitude is marked there, the temperatures varies from 10°C to 42°C.

Côte d'Ivoire comprises three major agro-ecological zones: dense rainforest (or Guinean zone) in the south, wet savanna (or Sudanese zone) in the north, forest-savanna transition zone (or Sudano-Guineen zone) in the center. The Guinean zone is undoubtedly the most densely populated, due to the strong migrations of which it was the object. The forest area, which accounts for 47% of the total area of the national territory, accounts for 78% of the total population, compared with 22% for the savanna zone. One of the consequences of this phenomenon is the pressure on arable land and severe forest cover (Figure 1).

Livestock is still a secondary economic activity with a direct contribution of about 4.5% to agricultural GDP and 2% to total GDP (PIB), it is nevertheless an important activity contributing to the improvement of food security, Diversification and increased incomes of farmers and livestock farmers, improved balance of payments and the preservation and improvement of the environment.

Most of the amount of agricultural residues has so far been used as compost for the recovery of organic matter and for soil fertility. This valuation is part of a logic to improve the productivity of Ivorian farms. It is a direct method of utilizing organic waste material, which is then spread over the whole crop area or concentrated at the level of mounds, which are used as supports for crops, where it will be degraded relatively slowly by microorganisms. At the same time, a significant fraction of post-harvest and processing plant residues are generally used as animal feed, where they are reduced and converted to animal waste.

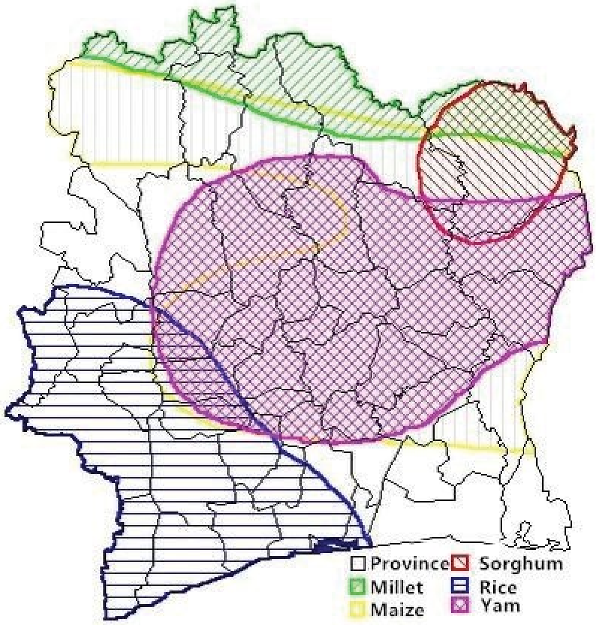

Figure 1: Main areas of cultivation of Côte d'Ivoire (source FAO 1996).

In addition, a significant share of agricultural waste is used as a source of secondary thermal energy by households and agro-food processing units. The energy contained in the biomass is released to produce electricity. The most proven processes have been the generation of electricity and cogeneration by combustion / steam or gasification / steam of woody resources and organic residues. These residues have already been used as fuels for self-generation of steam and electricity for industrial processes. The Ivorian agro-industry has a long experience: ex SODESUCRE (4 sugar factories used bagasse to produce 50 megawatts), ex: PALMINDUSTRIE (12 oil mills using palm waste to produce 25 megawatts), TRITURAF (using the seed hulls of Cotton to produce 2 megawatts, THANRY (1.5 megawatt production with forest residues) and SICOR, (1 megawatt production by burning coconut residues) [6].

Situation of the energy sector in Côte d'ivoire

The most commonly used energy sources in Côte d'Ivoire are biomass, electricity and petroleum resources. The wind and solar potential is not negligible but is still in its experimental phase.

Firewood, charcoal and agricultural wastes are the main energy resource in the country. For example, 21 million tons of wood are harvested each year from agricultural clearing and specific cuts (Environment Directorate, 2000). This form of energy which is essentially derived from the forest is the most used in Africa for cooking needs. However, the intensive exploitation of reserves for charcoal production and subsequent deforestation endanger the sustainability of this source of energy and dangerously affects the environment.

The country has been a major exporter of electricity towards Ghana, Burkina Faso, Togo and Benin. Originally, it was mainly the surplus of hydraulic capacity but since the 1990s, thermal capacity has begun to play an increasingly important role and now accounts for more than half of the two thirds of the energy produced. Electricity exports revenue was around $ 100 million in 2002 but fell to $ 32 million in 2009, due to the increase of domestic demand, but also due to a lack of investment or new production units. In fact, in early 2010, the country experienced its first major revolving load shedding, forcing the government to lease commercially powered diesel-powered generators at great expenses. This directly contributed to the estimated fall in internal GDP to 3% in 2010, from 3.8% in the previous year.

Petroleum resources are of great use especially for industrialization. Petroleum derivatives, including butane gas, contribute greatly to improve the living conditions of populations through their multiple uses (cooking, transport, industry, fertilizers, etc.). Butane gas supports biomass energy but its use is limited because it is not accessible enough to the rural populations because of its inadequacy to their way of life. On the other hand, in urban areas, its use is increasingly common, although the adoption rate is low owing to factors such as the high cost of kitchen equipment (gas cylinder cost, recharge price and the price of the gas cooker).

Methods of assessment of residues

The methodology initiated by Owen [1] and Balch [2] was used in this evaluation. It was developed on the basis of statistical data from FAO and other structures relating to agricultural production.

This assessment consisted of determining the quantities of residues generated in agricultural production and livestock production. Then, the equivalent biogas volumes for each type of residue were estimated using productivity indices.

Data on agricultural and livestock residues are obtained from the agricultural and livestock statistics (2010) of the documentation of the Ministry of Agriculture of Côte d'Ivoire, CEPICI, INS, UNDP and studies carried out By FAO on data on agro-industrial residues and agro-industrial by- products from West African countries. MS and MV levels are generally obtained gravimetrically, respectively, after drying at 105°C during 24 hours, from the measurement of the loss on ignition at 550°C during 2 hours. Similarly, the respective methane productivity of the different cultures have been collected in the literature.

Agricultural residues: The annual methane production potential of agricultural residues has been estimated from the volatile matter (QMV) of the residues. This amount of volatile material was calculated from the relationship (1).

$$QMV = Mi \times C_{res} \times MS \times MV(\%MS) \qquad (1)$$

The biogas potential of agricultural solid residues (P_i) was evaluated from equation (2).

$$P_i = QMV \times C_p \quad (2)$$

The relations (1) and (2) combined give the relation (3):

$$P_i = (M_i \times C_{res} \times MS \times MV(\%MS)) \times C_p \qquad (3)$$

M_i : Mass of production of the crop considered (tons),

C_{res} : Coefficient expressing the quantity of residues generated in accordance with agricultural production,

MS: Proportion of dry matter contained in residues,

MV(%MS) : Proportion of volatile matter contained in the residues, in (%MS).

C_p : Methane productivity index.

Values of Mi of the different cultures and their culture zone are given in Table 1. Values of Cres, MS, MV and C_p used are reported in Table 2.

Values of Pi of the different cultures are reported in Table 3.

Animal manure: The model for calculating the biogas production potential of manure from each type of farm is similar to that of agricultural residues. The quantity of volatile material QMV was calculated from the relation (4).

$$QMV= POP_i \times Wi \times MS \times MV(\%MS) \qquad (4)$$

The biogas potential of animal excrement (Pi) was evaluated from equation (5).

$$P_i = QMV \times C_p \times 365 \qquad (5)$$

The relations (4) and (5) combined give the relation (6)

$$P_i\,(m^3) = POP_i \times W_i \times MS \times MV(\%MS) \times C_p \times 365 \quad (6)$$

POP_i: Animal population of the type of livestock considered,

Wi : Daily quantity of organic matter (kg/head), animal.

MS: Proportion of dry matter contained in manure,

MV: Proportion of volatile matter contained in manure, in (%MS)

C_p : Methane productivity index,

365 : Number of days in the year.

Values of POP_i of the different animals are reported in Table 4. Values of W_i, MS, MV and C_p used are reported in Table 5.

Values of Pi of the different animal species are reported in the Table 6.

Calorific value of biogas: The calorific value of biogas is proportional to its methane content. The lower calorific value of biogas with a methane percentage of between 50 and 70% at 15°C and normal atmospheric pressure varies between 485 and 679 kWh/m^3.

Results

The results of the assessment of the deposits take into account 12 categories of residues of the 7 main crops selected. They are: sugar cane, plantain, cassava, yam, maize, rice, sorghum. Deposits of cattle, pigs and pigs were also evaluated. The year 2010 was chosen as a reference.

Culture	M_i (tons)	Areas
Rice	787000	South, South-West, Savanna zone
Corn	640000	Savanna zone, Haut-sassandra
Cassava	2600000	whole country
Yam	600000	whole country
Plantain banana	1700000	whole country
Sugar cane	1900000	Industrial Group
Sorghum	45000	Extreme North, Savanna area

Table 1: Main agricultural and agro-industrial product of Côte d'Ivoire in 2010 (M_i), Geographical departments and agro-ecological zones of the exploited areas.

Residues	C_{res}	MS (%)	MV (%(MS))	C_p of CH_4 (m^3/t MV)
Rice straw	0.6	40	65	242
Rice balls	5.0	50	90	189
Corn stalks	0.4	70	90	189
Corn rakes	5.0	85	80	189
Cassava leaves	0.1	30	40	123
Cassava peels	0.6	20	75	267
Yam leaves	0.1	30	40	123
Yam peels	0.6	20	75	267
Stalk and leaves of p. banana	2.2	5	60	123
Peels of plantain banana	0.3	20	89	322
Bagasse of sugar cane	0.4	54	94	200
Stalk of sorghum	0.5	55	65	134

Table 2: Proportion of dry matter (MS), proportion of volatile matter (MV), methane productivity index in m^3/t de MV (C_p), and coefficient expressing the quantity of residues generated in relation to agricultural production (C_{res}) [8]

Residues	QMV (tons)	P_i (m^3)
Rice straw	102310	24759020
Rice balls	1770750	334671750
Corn stalks	161280	30481920
Corn rakes	2176000	411264000
Cassava leaves	31200	3837600
Cassava peels	234000	62418000
Yam leaves	7200	885600
Yam peels	54000	14418000
Stalk and leaves of p. banana	112200	13800600
Peels of plantain banana	90780	29231160
Bagasse of sugar cane	385776	77155200
Stalk of sorghum	8043.75	1077862.5
TOTAL	**5133540**	**1E+09**

Table 3: Methane potential P_i (m^3) and quantity of volatile matter QMV (tons) of agricultural residues.

	Cattle	Pigs	Chicken(laying)
	(250-400 kg)	(30-80 kg)	(2-3 kg)
Animal(head)	1581582	348590	3261429
Quantity(tons)	514000	19200	8150

Table 4: Livestock numbers of cattle, pigs and chickens in Côte d'Ivoire in 2010.

Animal droppings	W_i in (tons/day/animal)	MS (%)	MV(%MS)	C_p of CH4 (m^3 /t MV)
Dung of Bovine	0.0045	15	55	75
Manure of Porcine	0.0020	15	35	275
Droppings of chicken	0.0110	30	60	175

Table 5: Daily quantity of organic matter W_i in (tons/day/animal), dry matter ratio (MS), volatile matter ratio (MV), and methane productivity index C_p in (m^3/tons of MV) of Bovine, porcine and chicken discharges [8].

Animal droppings	QMV (tons/an)	Cp of CH_4 (m^3)
Dung of Bovine	190.82	5223765.9
Manure of Porcine	2.016	202356
Chicken droppings	16.137	1030750.9
TOTAL	**208.358**	**6456872.8**

Table 6: Methane potential Pi (m3) and quantity of volatile matter QMV (tons/an) of cattle, pigs and chickens discharges.

Potential of crop residues

Table 1 shows the 12 major crops in Côte d'Ivoire for 2010, relative to the masses of their mains products and their respective agroecological zones of production. Data on noble crops from these crops were collected from the FAO Statistics [7].

Potential of animal waste deposits

Table 4 presents the estimation of cattle, pig and chicken population numbers for 2010, according to INS (2010). Experimental data about the specific production of livestock manure, dry matter and organic matter, and the specific methanogenic potential of these animal residues were collected. The default values for these estimations were used. They allowed a pessimistic assessment of the total deposits of cattle, pigs and chickens in Côte d'Ivoire. These data are presented in Table 5.

Table 6 presents an estimation of the potentials of specific deposits of bovine, porcine and chicken, raw material, dry matter, volatile matter and m^3 of methane per ton of organic matter for the year 2010. Total excreta deposits of the retained animals were estimated to be more than 2×10^5 tons of MV, equivalent to an ultimate methane potential of more than 6 x 106 m^3 of methane or about 3.6×10^6 MWh of electricity, convertible, in the specific case of Côte d'Ivoire.

Discussion

The Savanna zones offer favourable pedologic and climate conditions to the cultivation of corn and rice, that explains the strong presence of the residues of these crops in these regions. The total amount of biogas estimated from the residues of corn and rice is 441×10^6 and 358×106 m^3, respectively. The biogas potential of agricultural residues is mainly based on both corn and rice crops. This result could be linked to the agricultural policy of Côte d'ivoire, which promotes the cultivation of these plants and the fact that Côte d'ivoire has many agro-ecological zones favourable to their cultivation [8].

Concerning livestock manure, dung of bovine has the most important contribution in biogas potential. Its contribution is 81% of the total volume of biogas from animal manure. This could be explained by the fact that Côte d'ivoire includes agro-ecological zones favourable to livestock in general and cattle in particular.

To sum up, these results above highlight the potential of biogas production that is contained in agricultural residues.

Despite the enormous potential in organic substrates for the production of biogas in Côte d'ivoire, the country still does not have a biogas production unit. This could be explained by the lack of policy of vulgarization of biogas production units in the rural environment [9].

The unequal distribution of populations as well as cultural surfaces could explain the disparities in the distribution of substrates (livestock waste, agricultural residues) in the various localities of the country [10]. The choice of methodology and technology for the installation of biogas units in the country could be done on the basis of this unequal relocation. In fact, the exploitation of organic substrates (animal feces and plant residues) in rural areas could be done in small biogas units to satisfy partially, domestic energy needs [11].

However, the optimization of the cost of agricultural waste transport would be necessary to estimate the economic profitability of the production of this type of energy. In addition, small units of production capacity of 6 m^3 could be installed on the breeding sites of the country to solve, at least partially, the energy needs of the rural environment. This approach has been successfully used in China and India [12].

On the other hand, solid digestate fertilizes and improves agricultural soil structures, while reducing the risk of agro-chemical pollution of surface and groundwater [13]. It is also transformed into compost after maturation or used as a substrate for the production of lombri-compost and fungus. The digester liquid plays a role as a pesticide for annual crops, it is used as a source of nutrients in aquaculture or as an inoculum for anaerobic digestion [14].

The results showed that agricultural waste contained a large volume of biogas. However, the production of biogas from these wastes requires pre-treatment technology of garbage prior to digestion. Moreover, the optimization of the parameters for the methanisation process makes the use of these substrates complex. The production of biogas by these substrates for domestic use is therefore not to be advised. However, they could be produced in industrial fermentation units.

Conclusion

The total deposits of plant and animal residues for 2010 were estimated to be more than 5.0×10^6 tons of organic matter or the equivalent of more than 10×10^8 m^3 of methane in terms of energy potential by anaerobic digestion. These results put into perspective opportunities such as access to energy for the benefit of rural communities in Cote d'Ivoire through anaerobic digestion as well as more sustainable way of recovering agricultural residues available locally in significant quantities. However, estimation of ultimate methanogenic potentials did not account for the kinetics of substrate decomposition, anaerobic digestion processes, physical environment parameters, and socio-economic and political considerations. Moreover, this work does not include exhaustiveness or extreme precision in the quantitative evaluation of residual deposits. It nevertheless includes an indication value by underestimation, based on pessimistic choices in the determination of estimated parameters. Further studies corroborated by field surveys will need to refine this assessment for smaller time intervals and considering a finer geographical mesh. In addition, similar estimation exercises can be carried out on the fermentable fractions of household waste generated in cities, in order to also approach an assessment of the potentials of fermentable organic waste deposits and the conditions for the valorization of these resources.

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